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A Technique of Obtaining Cloud Moving Vectors from Cloud Images of the Geostationary Meteorological Satellite for Presuming a Large-Scale Wind Field

Inoue, Y.*[1], Kaga, A.*[2], Kayama, N.*[3], and Yamamoto, K.*[4]

*1 Dep. of Environmental Engineering, Osaka University,
2-1, Yamada-Oka, Suita, Osaka 565-0871, Japan
Tel:+81-6-6879-7669 / FAX:+81-6-6879-7669
E-mail: inoue@env.eng.osaka-u.ac.jp
*2 Dep. of Environmental Engineering, Osaka University, Japan
*3 Iwatani International Co. Ltd., Japan
*4 Sankyo Fronter Co. Ltd., Japan

Abstract: Now, the acid rain has become one of the environmental problems of global scales. In many cases, the cause substances of the acid rain are transported through a long distance. Therefore, the acid rain is not considered as domestic problems only. The long distance transportation model has been developed one technique for solving the long distance transportation problems of the cause substances of such acidifying. In this model, presumption of a wind field is the most important factor.

In order to apply this model to the East Asia area, we tried the presumption of the wind field using the cloud picture obtained from the GMS-5 (Geostational Meteorological Satellite 5.) We verified the accuracy of this wind field presumption technique by comparing mutually between the presumed technique of this wind field, the wind vector obtained by the meteorological Agency Japan, upper-layers weather data, and the GPV (Grid Point Value) data. In addition, the presumed wind field in East Asia was corrected so that the equation of continuity might be satisfied using MASCON model.

Keywords: Wind Vector, GMS-5, East Asia, Long-Distance Transport, Acid Rain

1. Introduction

Now, the acid-rain problem is counted as one of the global environmental problems. Since substances becoming the cause of rainwater acidification is conveyed to long distance across the border, it is unsolvable in many cases in the short term as an environmental problem within a country. Also in Japan, rainwater shows widely the tendency of acidification. It is presumed that 50% or more of the sulfuric acid ion in rainwater is coming from foreign countries in East Asia. The long-distance transport models have been developed as one of the elucidation techniques of the problem that carries out the long-distance transport of such acidification substances. Various phenomena, such as the transport by advection, diffusion, chemical reaction, change of phase, and removal by rainfall, are participating in long-distance transport process. However, the transport by advection is the most fundamental mechanism and the presumption of a precise wind field is the most important. It is required that the presumed wind field does not have lack of data in time and space. It may be required for some types of transportation formula that the equation of continuity is satisfied. The purpose of this study is discussing the technique of presuming the large-scale wind field in East Asia with sufficient accuracy for solving the long-distance transport of the acidification substance in East Asia. We considered using the cloud images obtained from the Geostationary Meteorological Satellite (GMS) as a wind field presuming method. The method using cloud images obtains wind data by determining the amount of the movement of a cloud using a serious of cloud images taken from the GMS at intervals of fixed time.

In this paper, a new method of wind field presumption by tracking the cloud movement is proposed. The accuracy of the method was examined by comparing with other data that were able to come to hand, such as upper-layers weather data. Finally, the presumed wind field in East Asia was corrected so that the equation of continuity might be satisfied using MASCON model (Dickerson, 1978).

2. GMS Wind Data

As a method of presuming the wind field in East Asia, the amount of cloud movement was determined using the infrared images obtained from the GMS-5, and the migration velocity of a cloud is assumed to correspond to the wind velocity. These images are created by changing the temperature data into intensity, and are expressed so white that temperature is low. The amount of cloud movements was determined using the PIV method. Since the image consists of the temperature distribution of the top layer of clouds and the wind velocity is generally as high as the upper layer, the migration velocity of each portion of an image differs and a large interrogation area cannot be used theoretically. However, since cloud images are more indistinct than visualized images generally obtained in a laboratory, mistaking vectors generates frequently by PIV using directly a small interrogation area. Then, first the difference of cloud height was disregarded and a rough velocity distribution of the whole place on a coarse mesh was obtained with a large interrogation area, and next the velocity at each point on a fine mesh was obtained with a small interrogation area with limited tracking zone referring to the interpolated vector of the rough estimation. The atmospheric pressure of the vector extraction point was also calculated using the average temperature within the interrogation area. Since the wind field at low layer (height of about 1500m) is important in long-distance transport of pollutants and a high geographical feature will disturb a cloud from drifting with the wind, the mesh points with an altitude of 1000m or more was eliminated from vector extraction point.

3. Wind Data Used

3.1 Monthly report of meteorological satellite observation (CMW data)

This data is calculated 4 times per day (00, 06, 12, 18UTC) by the GMS Cloud Moving Wind Evaluation System of the Meteorological Agency (Kato, 1983). Hereafter, we referred this data as cloud moving wind data (CMW data). The CMW data is calculated from the amount of cloud movement obtained from a serious of three GMS cloud images with 30 minutes intervals. The contents of the used data are latitude [degree], longitude [degree], wind direction [degree], wind velocity [m/s], setting altitude [hPa], actual altitude [hPa] and temperature [degree] of a cloud at the point after movement.

3.2 Weekly report of GPV wind data (GPV data)

This data is the presumed value based on the numerical model, which the Meteorological Agency uses for the weather forecast for a week. Hereafter, we referred this data as GPV data. The contents of the used data are U component [m/s], V component [m/s], and temperature [degree] in every grid point in isobaric surface of 850hPa (altitude is about 1500m). The number of grids is 25x23, and the distribution of the data is carried out once (12UTC) every day. The coordinate system by polar stereo projective method is used for grid point coordinates.

3.3 Daily report of observation data (ULW data)

This data is observed 4 times per day (00, 06, 12, 18UTC) in various places in the world using a radiosonde. Hereafter, we referred this data as upper layers wind data (ULW data). The contents of the used data are date, time, latitude [degree], longitude [degree], atmospheric pressure [hPa], temperature [K], the direction of wind [degree], and wind velocity [m/s]. Although the number of the points and altitudes of observation varies with time, there is usually very few data.

4. Mutual Comparison between Each Data

4.1 Comparison Method of Data

Two kinds of wind data were compared using the magnitude of vector difference and the difference of vector direction angle on the coordinate system of GMS (Mercator coordinate system).

4.2 Comparison Result

The comparison result between each data is shown in Table 1. GPV and ULW, GPV and CMW, and GMS and CMW agreed very well: the average value of the vector difference was less than three pixels (the average value of the magnitude of GMS vectors was about 10 pixels) and the average value of direction angle difference was less than 30 degrees.

Since GMS and CMW uses the same principle, coincidence was expected. GPV may be computed with reference to ULW and CMV. GMS and ULW were not in agreement: the average value of the vector difference was 11 pixels and the average value of direction angle difference was 54 degrees. It is considered to be the causes that there is few data of ULM and that interpolation for comparison was required since the observing points of both data were not in agreement.

Table 1 Comparison Result

	GMS	GPV	ULW	CMW
GMS		○	△	◎
GPV	○		◎	◎
ULW	△	◎		—
CMW	◎	◎	—	

◎: very well in agreement ○: well in agreement △: poor in agreement —: cannot compared

5. Interpolated Wind Field

The long-distance transport of pollutants is usually analyzed using the wind field in a low layer of 850hPa isobaric surface. Here the wind field in the layer without lack of data was presumed for every hour with temporal and spatial interpolation of three wind data, GMS, GPV and ULW. A weight function was used for the interpolation.

5.1 Interpolation

The interpolation was executed by equation (1).

$$f(x,y) = \frac{\sum_{k=1}^{N} f_k W(r_k)}{\sum_{k=1}^{N} W(r_k)} \qquad (1)$$

Here, N is the total number of the wind data used for interpolation, f_k is the value of k-th wind data (u_k or v_k), $W(r_k)$ is a weight function given by equation (2), r_k is an equivalent distance explained below between a grid point (I, J) and the k-th data point.

$$W(r_k) = \frac{1}{{r_k}^2} \qquad (2)$$

5.2 Equivalent Distance

For the data at the same time and the same altitude data, the equivalent distance r_k is the real horizontal distance between two points. However, in interpolating from the data at different time or different altitude, the difference in time and altitude has to be converted into equivalent horizontal distance. Here, the spatial correlation of wind vectors with different altitudes and the temporal correlations were calculated from GPV and ULM data, and the vertical distance and lapsed time were converted into the equivalent horizontal distance *DP* and *DT* that indicated the same amount of correlation factor decrease. Consequently, the time distance *DT* to time interval *T* [hr] and the vertical distance *DP* to barometric pressure difference *P* [hPa] were given with equation (3) and (4), respectively. If horizontal space distance is set to *DH* [km], the equivalent distance r_k is calculated by the equation (5).

$$DT = 30.17 \times T \quad [\text{km}] \tag{3}$$

$$DP = 1.703 \times P \quad [\text{km}] \tag{4}$$

$$r_k = \sqrt{DH^2 + DT^2 + DP^2} \qquad [\text{km}] \tag{5}$$

5.3 Interpolated Result of Wind Field

An example of interpolated result calculated from GMS data, GPV data, and ULW data is shown in Fig. 1.

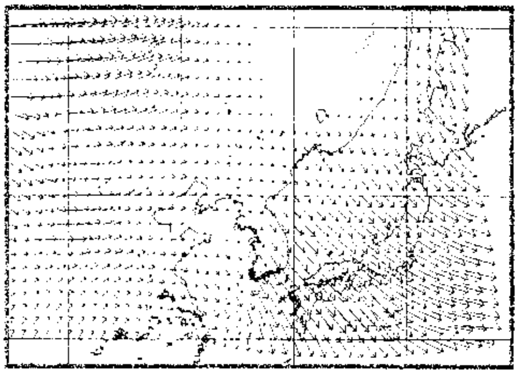

Fig. 1. Example of interpolated wind field (00UTC, 2nd December 1996)

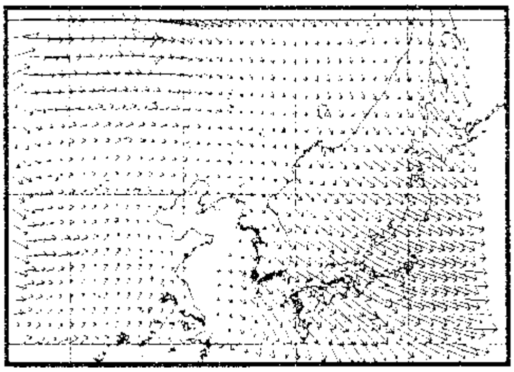

Fig. 2. Corrected wind field of figure 1

6. Correction of Interpolated Wind Field by MASCON Model

MASCON model (Dickerson, 1978) was used to correct an interpolated wind field so that the equation of continuity was satisfied. In this method, a wind field is corrected so that the integration of the sum of the square of the velocity correction amount and the square of the residual of the equation of continuity over the whole domain may become the minimum.

The functional using the equation of continuity expressed with spherical coordinates becomes the following equation.

$$E = \int_{\theta,\phi} \Big\{ \alpha_1^2 (\eta - \eta^*)^2 + \alpha_1^2 (v_\phi - v_\phi^*)^2 + \alpha_2^2 (v_r - v_r^*)^2 + \lambda \frac{1}{\sin\theta}\left(\frac{\partial \eta}{\partial \theta} + \frac{\partial v_\theta}{\partial \phi} + v_r \right) \Big\} r^2 d\phi d\theta \tag{6}$$

Here, $\eta = v_\theta \sin\theta$, ($v_r$, v_ϕ, v_θ) are the velocity components of corrected wind,(r, θ, ϕ) are radius, latitude and longitude, (α_1, α_2) are weight coefficients, λ is Lagrange multiplier , and * denotes the interpolated values.

From the conditions, which make this function the minimum, the wind field was solved, using the variation principle. The result is shown in Fig. 2.

7. Conclusion

A technique of modified PIV for application to GMS cloud images to get the wind data from cloud moving velocity was proposed. A method of presuming the wind field without spatial and temporal lack of data by using other wind data together with the wind data from GMS is also proposed. Furthermore, an example of the correction of a presumed wind field using MASCON model was also shown.

References

Dicherson, M. H.,1978, “MASCON-A Mass Consistent Atmospheric Flux Model for Regions with Complex Terrain,” J. Applied Meteorology, Vol.17, 241-253

Kato, K., 1983, “Extraction of Weather Elements Using Picture data of Geostationary Meteorological Satellite,” Weather Study Note (Kisyo Kenkyu Noto), Vol.148, 1-102